Industrial IoT in the Food Sector: A Scopus Bibliometric Mapping

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Abstract. This study uses bibliometric analysis of data from Scopus to map scientific output on the Industrial Internet of Things (IIoT) in the food sector between 2014 and 2025. Two approaches were applied: co-authorship by country and co-occurrence of all, author, and index keywords, with an overlay of the average year of publication. The results demonstrate an increasing volume of publications during this time period, the central role of the IoT/IIoT, and robust connections to Industry 4.0, machine learning, cybersecurity, and applications in energy and maintenance. Overlay analysis revealed new topics, such as digital twins, federated learning, and privacy-preserving techniques. The co-authorship network identifies leading research centers in the US, China, and Europe, as well as growing activity in the Middle East and Global South. This study provides a multi-layered picture of the thematic structure and evolution of the IIoT in the food industry. The findings can support researchers in identifying emerging research gaps, help policymakers prioritize investment in digitalization of the agri-food chain, and guide industry stakeholders such as food manufacturers and logistics providers in adopting IIoT solutions for improved traceability, efficiency, and sustainability.

1 Introduction

The Industrial Internet of Things (IIoT) is a pivotal technological catalyst for the Fourth Industrial Revolution. The integration of sensors, smart devices, cloud and edge computing systems facilitates the real-time collection, exchange and analysis of data by the IIoT. This is of particular significance within the food industry, given the elevated requirements for product safety, quality, and traceability, as well as the necessity for effective management of production and logistics processes [1, 2].

Recent studies have demonstrated significant advancements in intelligent food processing through the integration of artificial intelligence and deep learning with the Internet of Things (IoT) for tasks such as quality control, safety, and automation [1]. In the agri-food sector, particular attention is being paid to digital twins and blockchain for traceability and sustainability in food chains [3-5] . The concept of Food Informatics underscores the pivotal role of digitalisation in enhancing transparency and fostering trust, while concurrently identifying significant impediments such as substantial investment costs and the absence of comprehensive standards [6].

In the domain of logistics and supply chain management, the integration of the Internet of Things (IoT) and the Industrial Internet of Things (IIoT) technologies has been demonstrated to result in optimisation, enhanced transparency, and sustainability [7]. Beyond logistics, analogous applications also encompass energy-intensive sectors such as the oil and gas industry, where IIoT and edge computing facilitate reliable monitoring and predictable maintenance [8-10]. In the domain of renewable energy, IIoT–Edge architectures, encompassing software-defined networks, are already being employed in offshore wind farms to achieve scalability and sustainability [11].

In the context of industrial processes, the Internet of Things (IoT) is regarded as a transition from conventional automation to intelligent automation (see [12-14]). This integration of the IoT with blockchain, edge/fog computing, and artificial intelligence (AI) is a notable development in the field. The subjects of security, data management, and scalability of these solutions remain pivotal [15]. A particularly pertinent example is the water supply sector, where IIoT systems enhance the efficiency of treatment plants, yet concomitantly engender novel vulnerabilities to cyberattacks [16].

Bibliometric analyses on IIoT and its applications in the food industry remain limited. Despite the existence of systematic reviews in the agri-food sector [3,6], energy [11], and logistics [7], there remains an absence of systematic mapping of the research domains, countries, and institutions that dominate the field. The present study aims to address this lacuna through a bibliometric analysis of publications in the Scopus database for the period 2014–2025, employing co-

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authorship and co-occurrence analysis methods using VOSviewer. Despite rapid technological progress, there is still limited understanding of how scientific research on IIoT in the food sector has evolved over time, which countries and institutions are leading this domain, and which topics are emerging. A bibliometric mapping can address this gap and provide a systematic overview of the field.

2 Methodology

The bibliometric analysis was conducted with the aim of systematically mapping research activity related to the application of the Industrial Internet of Things (IIoT) in the food industry. The study is based on data extracted from the Scopus database on September 6, 2025, employing the following search query:

TITLE-ABS-KEY ("food industry" OR "food processing" OR "food production" OR "food supply chain" OR agri-food OR agrifood OR dair* OR meat* OR poultry OR fish* OR seafood OR cereal* OR grain* OR bakery OR bread OR confectioner* OR beverag* OR drink* OR fruit* OR vegetable* OR sugar OR oil OR fat*) AND TITLE-ABS-KEY ("Industrial Internet of Things" OR "IIoT" OR "Industrial IoT") AND NOT TITLE-ABS-KEY ("construction" OR "factory safety" OR "production chain") AND (LIMIT-TO(LANGUAGE,"English")) AND (EXCLUDE (DOCTYPE,"no") OR EXCLUDE (DOCTYPE,"er") OR EXCLUDE (DOCTYPE,"tb") OR EXCLUDE (DOCTYPE,"cr")).

The search covers the period 2014–2025 and includes only publications in English. The analysis encompasses the following document types: conference paper, article, book chapter, review, and book. Following the formulation of the search strategies, a total of 578 publications were identified. It is important to note that the Scopus database was selected as the foundation for the analysis due to the fact that an equivalent query in Web of Science (WoS) revealed that only 41 unique publications were available in the latter, while the remainder were already present in Scopus. In consideration of the distinctive nature of the WoS contribution, which is comparatively modest in scope when viewed in relation to the broader array of results encompassed by Scopus, it was determined that the execution of the bibliometric analysis would be undertaken on the basis of data derived from Scopus. This choice is also substantiated by a number of further considerations:

- Broader coverage – Scopus indexes a larger number of journals in the field of engineering and applied sciences, including topics such as IIoT and the food industry.
- Richer meta-information set – Scopus records contain both Author keywords and Index keywords, allowing for better mapping of subject areas and collaborative networks.
- Compatibility with tools – Scopus data is fully compatible with VOSviewer, which has specialized parsers for the Scopus CSV format.
- Practice in the literature – a number of bibliometric studies use only one database (most often Scopus), clearly mentioning this limitation [17-19].
- Limited informativeness of the WoS corpus – the 41 unique publications available are too few for reliable network analyses: the co-author network would be fragmented, the keywords insufficient for stable thematic clusters, citation links would be statistically weak, and resulting generalizations methodologically unreliable.

Therefore, although WoS adds a limited number of unique records, Scopus provides a more representative and technically convenient database for the purposes of this bibliometric analysis.
The VOSviewer software (version 1.6.20), a widely utilised instrument in bibliometric research, was employed for the purposes of visualisation and network analysis. VOSviewer facilitates the graphical representation of links between publications, authors, countries, and keywords based on frequency and co-occurrence.

In accordance with the methodological principles described by [20] and applied in similar bibliometric studies [21, 22], four main techniques are used in this analysis:

- Co-authorship analysis – in order to identify the leading authors, institutions, and countries, as well as the degree of scientific collaboration between them;
- Co-occurrence analysis – to determine the main thematic clusters and evolutionary trends in the field of IIoT in the food industry;
- Source analysis – to identify the journals and publishers that most frequently publish on the topic; and
- Citation analysis – to highlight the most influential publications and authors in the corpus. All analyses were performed using the full counting method, and to ensure the stability and validity of the results, different thresholds were applied depending on the type of analysis.

3 Results

3.1 Bibliometric Characteristics of Publications

In response to the request, which was limited to specific document types, it was determined that the majority of the publications were conference papers and journal articles (Fig. 1). In contrast, book chapters, review articles, and monographs constituted a significantly smaller proportion of the total.

This distribution indicates that research in the domain of Industrial Internet of Things (IIoT) within the food sector is predominantly disseminated through scientific conferences and specialized publications, while in-depth theoretical analyses and monographic studies remain limited. As demonstrated in Fig. 1, the predominance of conference publications indicates that the field remains in a technologically experimental and dynamically developing stage, in which novel concepts

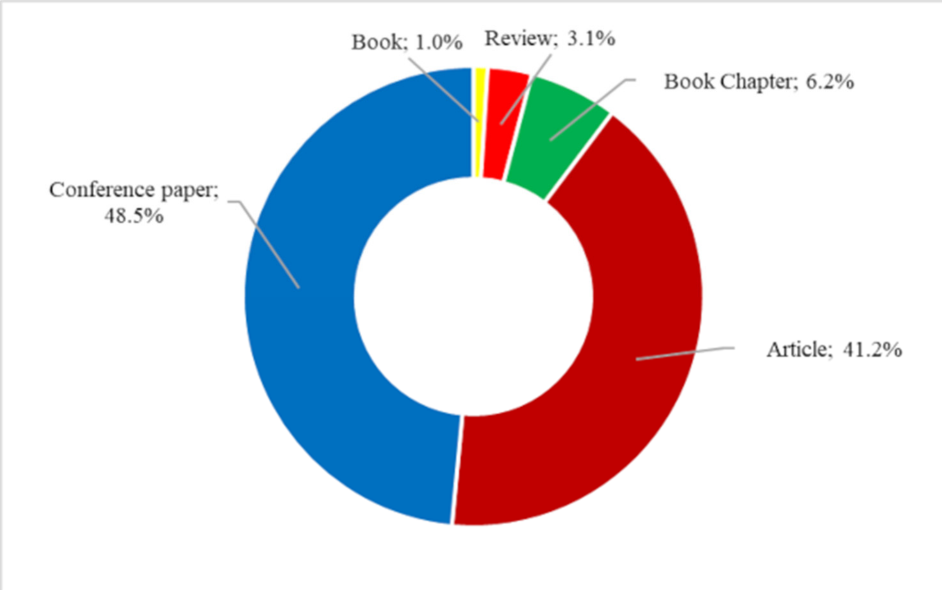

Fig. 1. Documents by type.

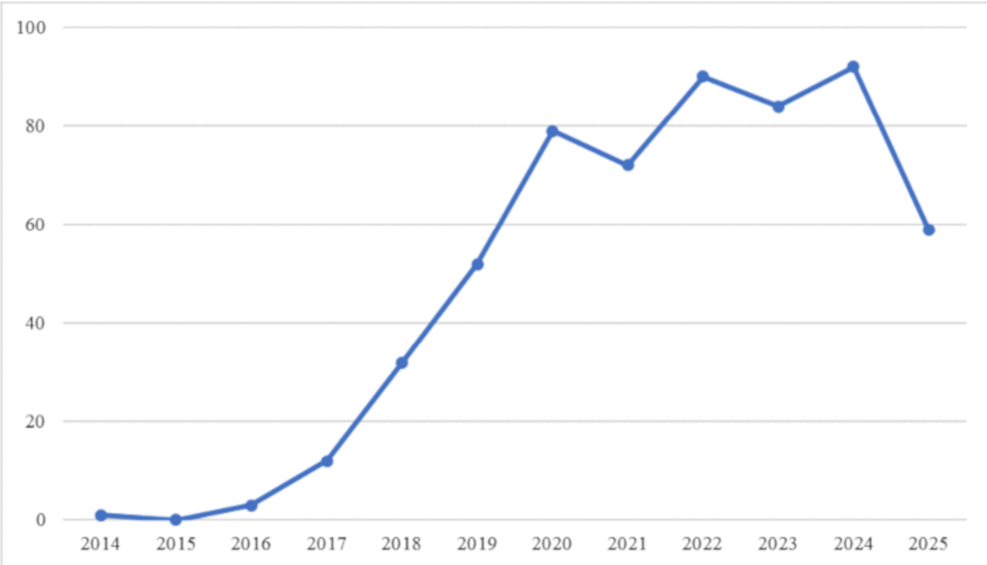

Fig. 2. Documents by year.

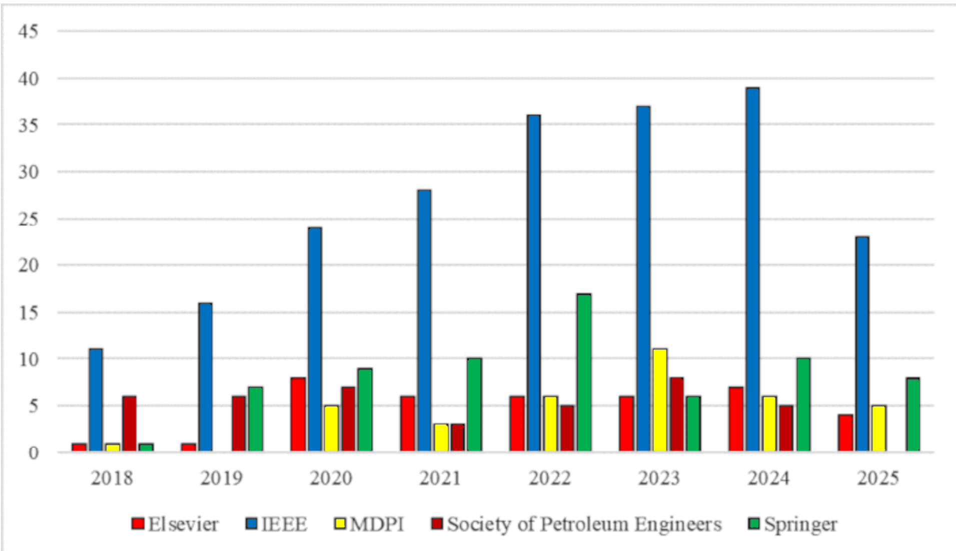

Fig. 3. Documents per year by source.

and applications are presented before being theoretically consolidated. The paucity of review papers and books in this field suggests that it has yet to attain bibliographic maturity. Its conceptual foundations are being established primarily through empirical and engineering research, rather than through systematic theoretical frameworks. This tendency aligns with broader patterns evident in the evolution of research related to Industry 4.0 and digitalization. Historically, these fields transition from a preeminence of conference papers to a more mature phase of publication in scientific journals as the body of knowledge within these domains progresses.

A chronological analysis of publications reveals a consistent increase in scientific interest between 2014 and 2025. As demonstrated in Fig. 2, a marked upward trend commenced in 2017, when the number of publications increased significantly and subsequently stabilized at a relatively high level. The observed peak in 2024 signifies the culmination of research activity in this domain, while the lower values recorded for 2025 are attributable to incomplete data for the current year.

This temporal evolution illustrates the progressive maturation of IIoT research within the food sector, transitioning from initial conceptual studies toward more applied, system-oriented investigations. The observed acceleration after 2017 corresponds with the global proliferation of the Industry 4.0 paradigm, while the peak around 2023–2024 indicates the establishment of IIoT as a recognized and cross-cutting research field. The sustained high publication output further suggests a shift from technology demonstration to integration and interdisciplinary convergence, where themes such as data analytics, cybersecurity, and sustainability increasingly intersect within industrial food applications.

The number of documents published by the five leading publishers, Elsevier, IEEE, MDPI, Springer, and Society of Petroleum Engineers, exhibits a marked upward trend following 2018 (Fig. 3). This period was selected because the preceding years (2014–2017) were marked by sporadic publications on the subject, while it was subsequent to 2017 that IIoT research in the food sector commenced a regular appearance in the scientific publications of these publishers.

The data indicated that IEEE maintains a dominant position throughout the period under review, with steady growth from 11 publications in 2018 to a peak of 39 in 2024, reflecting the publisher's active role in the dissemination of engineering and technology research. Springer also demonstrates a consistent presence with a moderate but steady volume of publications, reaching its maximum in 2022 (17 documents).

Elsevier and MDPI follow with a more moderate but stable contribution, with Elsevier showing growth after 2020, while MDPI shows acceleration after 2022, which corresponds to the increased presence of open-access publications and interdisciplinary projects. The Society of Petroleum Engineers, which was initially active from 2018 to 2020, is gradually losing its leading position in the field. This shift is probably due to a shift in focus towards more specialized applications of IIoT in the food industry.

Developments after 2018 demonstrate consolidation and growth in scientific interest, with IEEE emerging as the primary catalyst of publication activity and other publishers contributing to the thematic expansion and interdisciplinary nature of research in the domain of the Industrial Internet of Things in the food sector.

China, India, and the United States are the primary contributors to scientific output in IIoT research in the food sector (Fig. 4). The United Kingdom and several other European countries, including Germany, Italy, and Spain, have demonstrated a more moderate yet stable presence. Outside Europe, Saudi Arabia, Australia, and Canada are noteworthy for their increased activity in this field.

The predominant positions of China and India are indicative of the outcomes of their national policies concerning digital transformation and accelerated IIoT infrastructure development. In contrast, the European contribution is marked by a more fragmented research model. This geographical configuration reveals the asymmetrical distribution of scientific capacity in the field of IIoT and the food industry, which is largely determined by differences in national innovation ecosystems and investment policy priorities.

The predominant role of China and India indicates that emerging economies are progressively assuming a leadership position in applied technology research. In contrast, Western Europe exhibits a more distributed pattern of activity, with a concentration on specialized subfields and international research collaborations rather than on the quantity of publications.

The increasing involvement of the Middle East and Asia-Pacific region signifies the gradual globalization of IIoT research, suggesting that the field is transitioning from a few predominant centers to a more interconnected and internationally diversified scientific landscape.

Fig. 5 depicts the disciplinary distribution of publications and indicates that the field is mainly driven by technological and engineering sciences. Contributions from other domains highlight its multidisciplinary nature.

This disciplinary profile demonstrates that research on IIoT in the food sector is still rooted in applied engineering and computer science, with an emphasis on hardware integration, communication protocols, and system optimisation. The limited, yet growing, participation of fields such as agriculture, management, and environmental science suggests that the topic is progressively evolving toward a more holistic understanding of digital transformation across the entire agri-food value chain. This multidisciplinary expansion reflects a shift from purely technological feasibility to broader issues of sustainability, traceability, and socio-economic impact, marking the transition of IIoT research from an engineering niche into a comprehensive domain of industrial and societal innovation.

The dynamics of citations by year (Fig. 6) reflect the same five leading publishers previously identified as

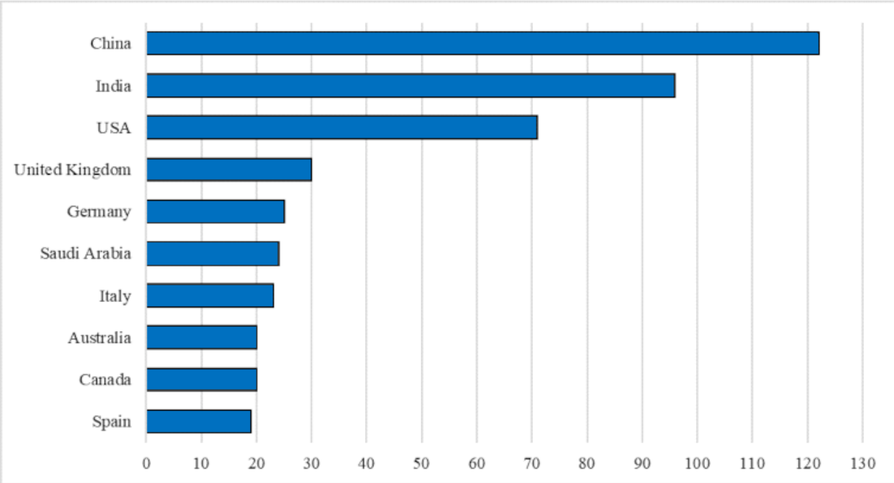

Fig. 4. Documents by country – up to 15 countries.

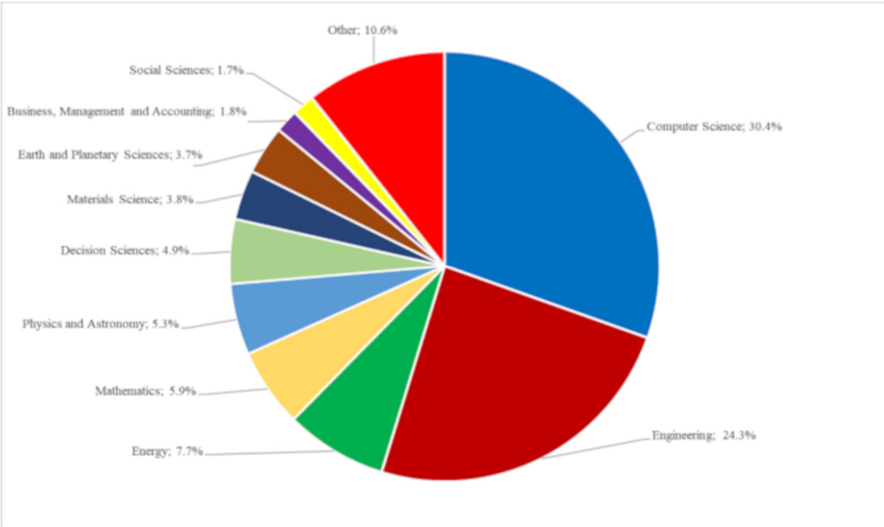

Fig. 5. Documents by subject area.

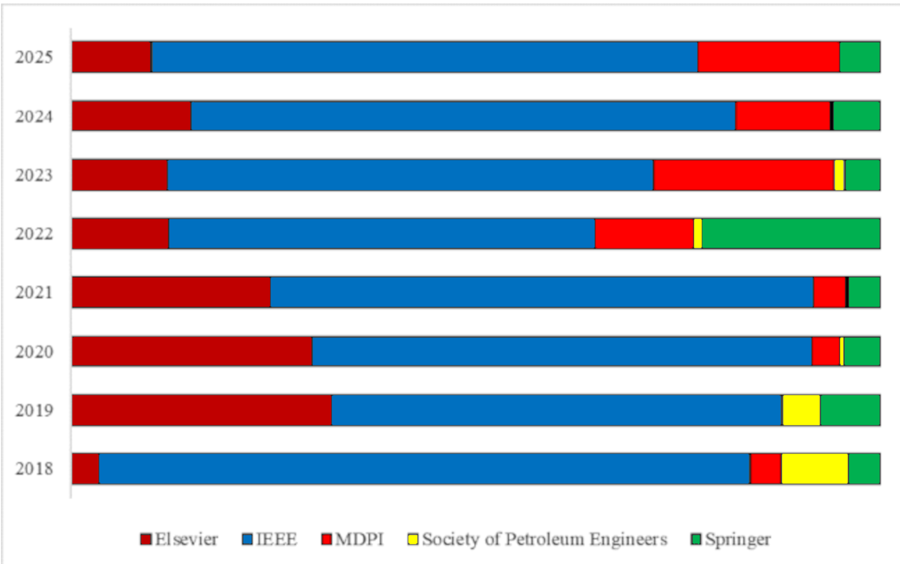

Fig. 6. Citation per year (5 most cited publishers).

having the highest publication output. This correspondence is expected, as publishers with a larger volume of publications naturally accumulate a higher number of citations. The most substantial citation activity is concentrated within Elsevier, IEEE, MDPI, Springer, and the Society of Petroleum Engineers, which collectively shape the scientific discourse in this domain. From 2018 to 2021, there was a significant increase in the number of publications and citations at Elsevier and IEEE, suggesting heightened academic engagement and technological advancement in the nascent stages of research. Elsevier reached its zenith in 2020, while IEEE maintained a stable and elevated number of citations between 2020 and 2021. Beginning in 2022, there has been a notable shift in focus toward MDPI and Springer, which have demonstrated a substantial increase, particularly from 2022 to 2023. This phenomenon is indicative of a growing trend toward more open and multidisciplinary publishing platforms, which have emerged as prominent venues for the discussion of contemporary issues such as cybersecurity, sustainability, and smart food systems. Concurrently, the Society of Petroleum Engineers' (SPE) activities, which were predominant in 2018, are undergoing a gradual decline, indicating a shift in scientific focus toward more specialized industrial and agri-food applications of the Industrial Internet of Things (IIoT).

Overall, the citation trajectory illustrates a broader transition from the dominance of traditional engineering-focused publishers toward more adaptable, interdisciplinary platforms. This phenomenon corresponds to the advancement of the research domain itself—from technological demonstrations to the incorporation of intelligent, interconnected, and sustainable solutions in the food industry.

3.2 International Co-authorship Networks

In the visualization conducted using VOSviewer for co-authorship between countries, different thresholds were tested for the minimum number of documents published by a country. With a threshold of 5 documents, 38 countries out of a total of 91 were included in the analysis. When the threshold was lowered to 4 documents, the number of countries increased to 45, and with a threshold of 3 documents, 51 countries were covered. At an even lower threshold of 2 documents, 56 countries were included in the analysis, while including all countries with at least 1 document resulted in the full set of 91 countries.

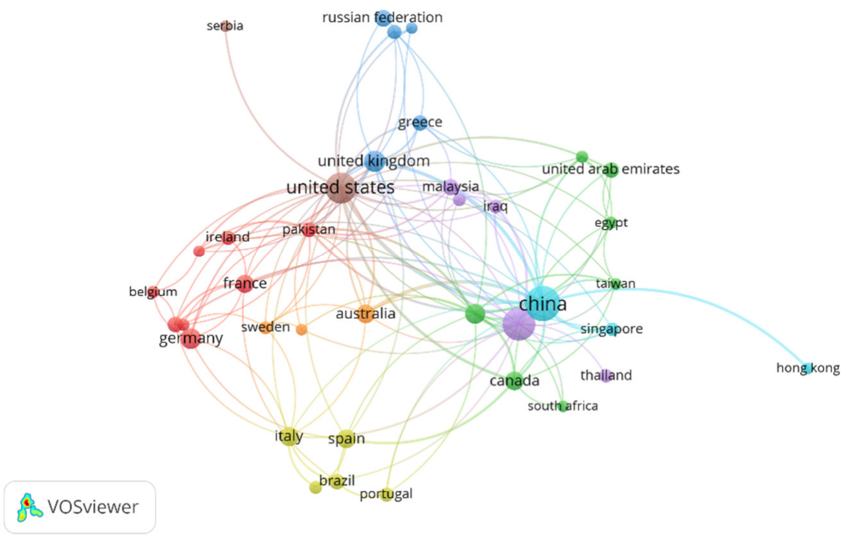

Fig.7. International co-authorship network at a threshold of 5 documents, clustered by countries.

This sequence clearly shows how the choice of threshold affects the inclusion of more or fewer countries in the international cooperation network. Higher thresholds allow for a focus on leading countries with more significant participation, while lower thresholds reveal a broader and more diverse picture of global cooperation.

In order to provide a clearer and more analytical picture of international cooperation, a threshold of 5 documents has been selected for the presentation of the results. This choice is balanced – on the one hand, it eliminates countries with limited participation, whose single publications do not make a significant contribution to the network; on the other hand, it includes a sufficiently large number of countries (38 out of 91) to highlight the main scientific centers and links between them.

As illustrated in Fig. 7, the data clearly delineates several primary clusters:

- The United States occupies a central position in the global network, with 47 connections (total connection strength 80) and strong interaction with key partners such as China, the United Kingdom, Canada, and Saudi Arabia.
- China also stands out as a global leader, with the largest number of documents (123 publications) and extensive international cooperation, including with India, Singapore, and Hong Kong.
- India is gradually establishing itself as a notable regional nexus, exhibiting dynamic

interconnections with Saudi Arabia, the United States, and Canada.

- European countries (Germany, France, Italy, Spain, and Norway) exhibit a high degree of interconnectedness, characterised by robust internal collaboration and extensive connections with the United States and China.
- Middle Eastern countries (Saudi Arabia, Egypt and the UAE) are exhibiting an increasing level of participation, with Saudi Arabia assuming a leading role and demonstrating a marked degree of collaboration (30 links, link strength 25).
- Smaller but well-connected participants include countries such as Singapore (high number of citations and an average of over 91 citations per publication), Hong Kong, as well as South Korea and Japan.

This configuration of international co-authorship indicates that research on IIoT in the food sector is developing in a highly centralized but interconnected global network. The United States and China are the two primary hubs, which serve to bring together peripheral and regional players to create an asymmetrical yet functionally integrated structure. This phenomenon is indicative of the geopolitical dynamics that characterise the realm of scientific production, wherein technological capacity and investment in digital infrastructure are pivotal factors in determining leadership within the field.

Concurrently, the escalating dynamism exhibited by countries in the Middle East and Asia signifies the progressive diffusion and decentralisation of knowledge, thereby engendering a conducive environment for enhanced international collaboration. The network clearly demonstrates that scientific research on IIoT is no longer limited to industrially developed economies, but is becoming a global research priority, supported by various models of funding, technology transfer, and regional strategic programs.

The second visualised option (Fig. 8) demonstrates the distribution of collaborations over time (2021–2023), thus revealing a trend towards increased international cooperation in recent years, particularly on the part of Egypt, Nigeria, and Thailand (average year of publication 2023).

In summary, the results at a threshold of five documents show a clearly structured network of international co-authorship, dominated by global scientific centres such as the US and China, which act as major hubs in the global research space. In addition, well-connected regional networks in Europe are noteworthy, as are emerging centres in the Middle East and developing countries that have shown increasing activity in recent years. In addition to the quantitative dimension, the quality of scientific contribution is also important, as evidenced by the high citation rates of publications in countries such as Singapore, Hong Kong, and Japan. This finding serves to substantiate the assertion that the selected threshold facilitates a balanced perspective on the predominant actors involved, whilst concomitantly enabling the monitoring of regional and temporal trends in global cooperation.

The temporal structure of international co-authorship demonstrates not only quantitative growth but also a qualitative rearrangement of global scientific ties. The intensification of collaborations after 2021 coincides with the period when topics such as digital twin, blockchain security, and AI-based predictive maintenance begin to dominate scientific research. This indicates that emerging participants, notably Egypt, Nigeria, and Thailand, are entering at a stage characterised by the practical implementation of IIoT rather than its theoretical exploration. This stage is characterised by the recognition of IIoT as a solution for specific industrial and infrastructure challenges.

Consequently, the paradigm of international cooperation is undergoing a transition from a model that is dominated by traditional industrial powers to a more inclusive, distributed research ecosystem. In this new ecosystem, developing countries are beginning to assume an active role in the transfer and adaptation of digital technologies. This trend underscores the assertion that the Internet of Things (IoT) is evolving into a globally accessible technology, the development of which is no longer contingent upon economic might, but rather on innovative strategies and the establishment of open partnerships between regions.

3.3 Keyword Co-occurrence Analysis

In order to delineate the primary thematic domains and their interrelations in the field under scrutiny, a co-occurrence analysis of keywords was conducted. This approach facilitates the identification of not only the most frequently occurring terms, but also the ways in which they are combined in scientific publications. This in turn reveals leading research clusters and emerging topics. Three distinct types of keywords were employed in the analysis: author keywords, index keywords, and all keywords. Author keywords refers to those words or phrases that a researcher chooses to define, thus reflecting their particular focus and perception of the essence of the research. Index keywords are added by the database for the purpose of unified categorization and facilitating searching, and are often more general in nature. It is evident that all keywords represent a combination of the two groups, thereby providing the broadest possible picture of the thematic structure. Each of these three types of keywords carries a different analytical emphasis – from the ”self-definition” of researchers, through the official systematization of scientific databases, to the overall presentation of the field. It is the comparison between them that enables the construction of a multifaceted and comprehensive representation of the evolution of scientific topics.

3.3.1 All Keywords

Following an experimental investigation into the relationship between the minimum number of occurrences of a keyword and the number of terms included, it was determined that the latter varied significantly. The number of terms included ranged from 4,901 keywords at threshold 1 to 261 keywords at

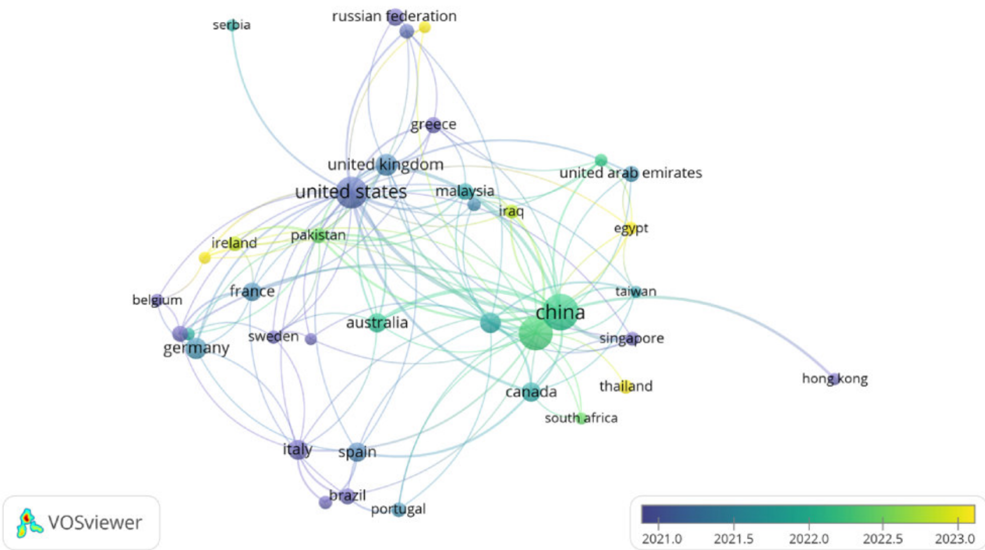

Fig. 8. International co-authorship network at a threshold of 5 documents, colored by average publication year

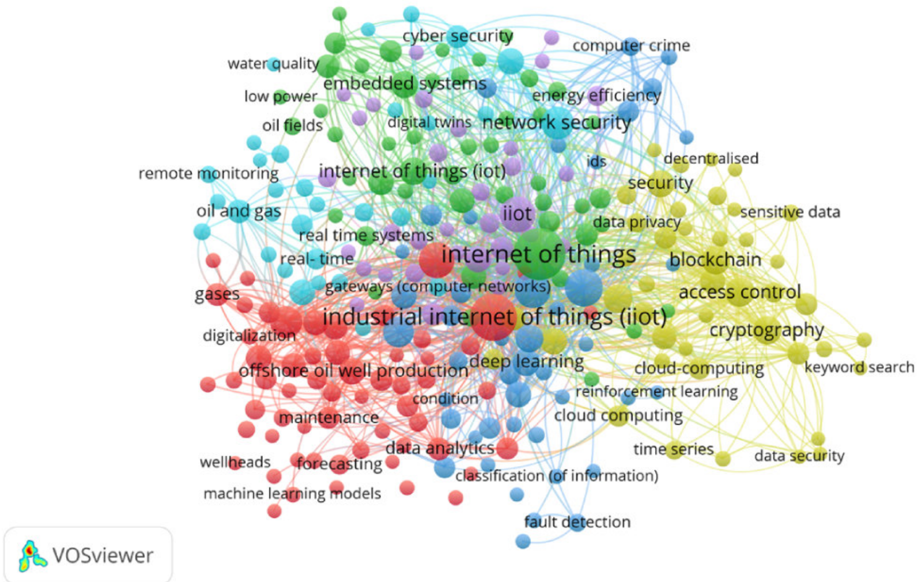

Fig. 9. Co-occurrence network of all keywords at a threshold of 5, clustered by thematic areas.

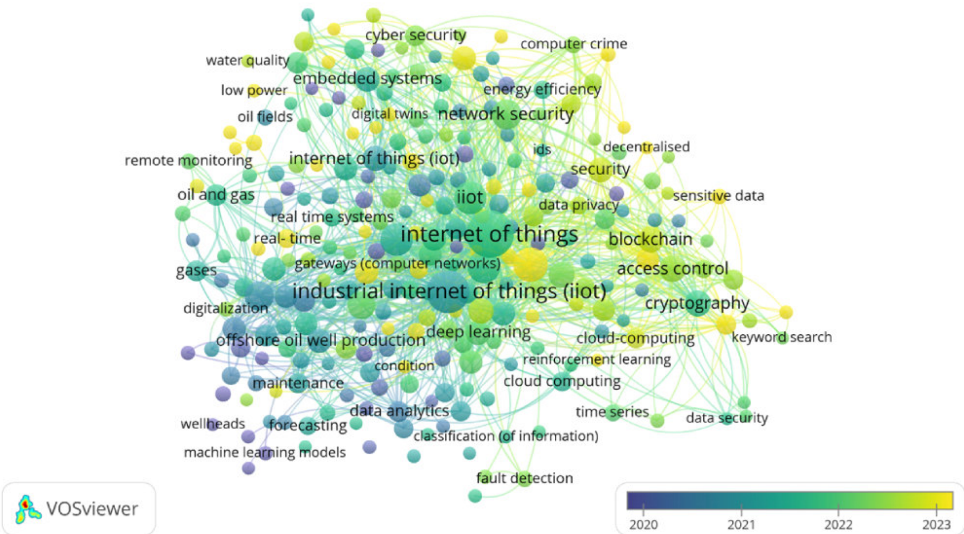

Fig. 10. Co-occurrence network of all keywords at a threshold of 5, colored by average publication year.

threshold 5. In order to circumvent an excessively diffuse and challenging-to-interpret image at low thresholds, and to attain a more lucid visualization that facilitates concentration on the most salient connections, threshold 5 was selected for the final analysis. At this threshold, out of a total of 4,901 keywords, only 261 meet the requirement, which provides a satisfactory balance between scope and analytical clarity. The resulting network is illustrated in Fig. 9, and the corresponding temporal overlay map is shown in Fig. 10.

The resulting network of keywords delineates clearly defined thematic clusters that reflect the leading research areas in the field.

The following clusters have been identified:

- Internet of Things (IoT) and Industrial IoT (IIoT)

The largest proportion of keywords is grouped around terms such as “internet of things” (206 occurrences), “industrial internet of things” (71 occurrences), “iiot” (70 occurrences), and related variants. These concepts bear a close relationship to those of “edge computing”, “cloud computing”, “big data”, and “machine learning”, thereby indicating that research in this field is concentrated on both technological infrastructures and the implementation of intelligent algorithms for data processing.

- Cybersecurity and data protection

The second prominent cluster encompasses a range of subjects related to cybersecurity, including “cyber physical systems” (19 occurrences), “network security” (54 occurrences), “cryptography” (38 occurrences), “blockchain” (38 occurrences), and other related terms. This finding underscores the centrality of research priorities pertaining to system reliability and security within the contexts of IIoT and Industry 4.0. More specific topics such as “privacy-preserving techniques”, “attribute-based encryption”, and “intrusion detection systems” are also strongly represented, underscoring the drive to develop robust and flexible data protection solutions.

- Artificial intelligence and machine learning

Key words such as “artificial intelligence” (26 occurrences), “machine learning” (45 occurrences), “deep learning” (32 occurrences), “convolutional neural networks” (7 occurrences), and "reinforcement learning" (5 occurrences) form a separate thematic cluster that is closely related to both IoT and applications in the field of industrial systems. It is significant that this group has a high average citation rate—for example, “deep learning” has an average of over 40 citations per publication, which indicates a strong impact on the scientific community.

- Industry 4.0 and intelligent manufacturing

Another clear focus is related to “industry 4.0” (72 occurrences), “intelligent manufacturing”, “smart manufacturing”, “digital transformation”, “digital twin”, and “supply chain management”. These topics reveal that research focuses on the digitization of manufacturing and the optimization of industrial processes, with a particularly strong link to IoT and AI.

- Energy and industrial applications

The network also includes a cluster focused on applications in the energy sector: power system, power transmission networks, oil and gas industry, and other industrial terms. Here, IoT technologies are seen as a means of optimising and ensuring the sustainability of energy and industrial processes.

- Emerging and interdisciplinary research directions

The overlay visualization highlights new keywords with a more recent average publication year, such as “federated learning”, “digitalization”, “adversarial machine learning”, “smart manufacturing”, and “privacy-preserving techniques”. This indicates rapidly expanding areas of research that combine traditional IoT topics with new methods for decentralized processing and security.

In summary, the analysis of the joint occurrence of keywords at a threshold of 5 shows a clearly defined structure of the research field. The prevailing themes pertain to the Internet of Things (IoT) and Industrial IoT, encompassing domains such as cybersecurity, machine learning, artificial intelligence, industrial applications, and Industry 4.0. Concurrently, the overlay visualization reveals the emergence of novel subjects such as federated learning, adversarial machine learning, and privacy-preserving techniques, which delineate contemporary trends and future directions of development. These results underscore two observations. First, they demonstrate the stability of established research areas. Second, they reveal the dynamics of emerging topics that will shape scientific research in the coming years.

When considered as a whole, these clusters reveal a multi-layered and hierarchically organized thematic structure, with the technological foundations (IoT and IIoT) functioning as a core that connects the higher conceptual areas of cybersecurity, artificial intelligence, and smart manufacturing. The close association of the terms “machine learning” and “cybersecurity” in network terminologies signifies an emerging convergence between data-driven analytical models and secure industrial communication architectures.

The joint positioning of “digital twin” and “Industry 4.0” reflects a transition from process digitization to virtual modeling and predictive optimization. This transition links classic industrial production with new-generation intelligent systems.

The overlay visualization shows that the field of research is shifting from infrastructure-oriented topics to cognitive and secure architectures. In these architectures, decentralized training methods and personal data protection are emerging as strategic priorities. The interconnection of these clusters demonstrates that the Industrial Internet of Things (IIoT) in the food industry is evolving into an integrated ecosystem, marking the transition from Industry 4.0 to Industry 5.0.

3.3.2 Author Keywords

When analyzing authors’ keywords, a threshold of five occurrences can facilitate the identification of those concepts that researchers consistently use to delineate the focus and contribution of their publications. In contrast to the comprehensive scope of all keywords, authors' terms offer insight into the manner in which the scientific community articulates the thematic identity of the field from within, through targeted discursive choices.

The study indicates that authors demonstrate a discernible predilection for concepts that accentuate the architectural, methodological, and applied characteristics of systems. Examples of such technologies include digital twin, federated learning, blockchain, and blockchain security. These technologies have emerged not only from advancements in technology but also from the pursuit of greater transparency, traceability, and autonomy of industrial processes. The high frequency of these keywords indicates that researchers perceive advanced algorithmic and cyber-physical solutions as a fundamental direction of development.

Furthermore, the author's incorporation of keywords serves to accentuate specific applications and research niches, which are not as distinctly delineated within the combined set. This includes terms related to the integration of intelligent systems, the optimization of production processes, and methods for secure data management in distributed environments. This finding serves to reinforce the prevailing understanding among researchers that the field is regarded as a dynamic space in which key technological concepts are closely linked to issues of reliability, autonomy, and scalability.

In summary, the analysis of authors' keywords not only emphasizes the thematic centers selected by the authors, but also exposes their strategic priorities. These strategic priorities include a concentration on intelligent, traceable, secure, and autonomously functioning industrial ecosystems. This concentration aligns with the dimensions of the future evolution of IIoT in the context of sustainable manufacturing.

3.3.3 Index Keywords

The analysis of index keywords at a threshold of five occurrences offers a different perspective from that of authors' terms. While authors introduce words that reflect their research intent, index keywords reflect the systematic classification performed by databases. This results in a more structured and, at times, broader thematic framework that incorporates concepts from domains in which IIoT is utilized as a tool, rather than exclusively as a subject of independent research.

In this perspective, subjects pertaining to industrial infrastructures, operational reliability, and the management of complex engineering processes are of particular relevance. The index classification is evidenced by terms such as "predictive maintenance", "power systems", "oil and gas", and related concepts, suggesting a high degree of automation and critical operational requirements in traditional sectors. This broadening of the thematic scope, which extends beyond the technological foundations, underscores the significance of pertinent contexts of implementation.

The index keywords also highlight areas where there is increased integration between security methodologies, data processing, and autonomous systems. The integration of concepts such as digital twin, federated learning, and privacy-preserving techniques within a comprehensive array of industrial terminologies signifies an endeavor to amalgamate established industrial standards with emerging forms of intelligence and secure digital infrastructure.

Consequently, the index classification delineates a thematic structure that is more balanced between technological concepts, industrial applications, and methodological approaches. Thus, this paradigm enables the tracking of not only the evolution of scientific discourse but also the actual directions in which IIoT is being implemented as a practical solution in complex manufacturing and energy systems.

3.3.4 Comparative Insights

A comparative analysis of the three types of analysis reveals that, despite their differences in focus, they are complementary and collectively provide a comprehensive overview of the research field. The utilization of all keywords ensures comprehensive coverage, thereby facilitating the visualization of the intricate structure inherent within the thematic domains. The keywords selected by the author emphasize novel and innovative subjects that researchers have identified as being of particular importance, including digital twin, federated learning, and blockchain security. Conversely, index keywords offer a more stable systematization, emphasizing sustainable domains such as the oil and gas industry, predictive maintenance, and classic technology cores. Across the three analytical approaches, IoT, IIoT, and cybersecurity consistently emerge as foundational cores that provide structure to the field. Consequently, the integration of these three analyses generates a multifaceted and balanced depiction, encompassing both the stability of established subjects and the dynamism of emerging domains.

3.3.5 Interpretation and Evolution of Thematic Clusters

A comprehensive evaluation of keyword networks reveals that research on the Industrial Internet of Things (IIoT) in the food sector is evolving across multiple interconnected thematic domains. These domains mirror both the technological sophistication and conceptual alignment that characterize the field.

The initial axis, infrastructure and connectivity, is predicated on the terms "Internet of Things", "Industrial IoT", "cloud computing", and "edge computing" and delineates the foundational technological stratum of smart industrial environments. These concepts dominated in the early period (2014–2018), when the focus was on the development of sensor networks, communication protocols, and data collection and transmission systems.

The second thematic axis, intelligence and autonomy, emerged during the subsequent phase and is distinguished by an escalating frequency of co-occurrence of keywords such as machine learning, deep learning, artificial intelligence, and predictive maintenance. The central position of IIoT research within the network indicates a transition from passive monitoring and control to active decision-making and cognitive automation. This stage signifies the transition from data-driven optimization to intelligent and self-learning manufacturing in the food industry.

The third primary thematic category is security and trust, encompassing concepts such as cybersecurity, blockchain, cryptography, and privacy-preserving techniques. The correlation between these terms demonstrates a mounting interconnection between artificial intelligence analytical methods and blockchain-based data protection mechanisms. This underscores the significance of ensuring the reliability and integrity of information for the widespread implementation of IIoT solutions in agri-food systems.

The fourth and most recent axis is sustainability and digital representation, defined by the emergence of terms such as “digital twin”, “energy efficiency”, and “federated learning”. These subjects, distinguished by a subsequent average publication year (2022–2025), mirror the scientific community's shift toward virtual modeling, decentralized learning, and environmentally conscious digitization. The concept of the digital twin serves as a critical link between cyber-physical monitoring and sustainability assessment in food production chains.

In summary, the interaction between these clusters reveals progressive integration—from technological connectivity to intelligent, secure, and sustainable ecosystems. The evolution of thematic areas indicates that the development of IIoT in the food industry has already transcended isolated technological solutions and is progressing towards a systemic model that integrates interoperability, trust, and environmental awareness—key characteristics of the emerging Industry 5.0 paradigm.

4 Conclusion

A bibliometric analysis reveals a growing scientific interest in the application of the Industrial Internet of Things (IIoT) in the food industry during the period 2014–2025. China, India, and the United States are the most significant contributors, constituting the global core of research, while Europe is distinguished by more fragmented but stable activity. The primary research domains encompass the digitization of production, cybersecurity, machine learning, artificial intelligence, and Industry 4.0 concepts. In recent years, novel subjects such as digital twins, federated learning, and privacy-preserving techniques have emerged within this field.

The findings indicate a shift in the field's focus from infrastructure-oriented research centered on connectivity and data collection to integrated ecosystems where autonomy, security, and sustainability are interconnected. The cluster analysis corroborates this evolution, demonstrating a transition from the inaugural technological phase of establishing IoT infrastructures to the present stage, which is distinguished by intelligent architectures underpinned by artificial intelligence, blockchain technology, and decentralized data processing methodologies. This dynamic is indicative of the gradual emergence of the Industry 5.0 paradigm, which seeks a balance between efficiency, reliability, and environmental sustainability.

The primary contribution of this study is threefold: first, it provides a systematic mapping of the scientific field; second, it identifies leading countries and research clusters; and third, it analyzes emerging trends. This provides a valuable starting point for researchers, policymakers, and industry when planning strategies for digitizing the food chain and integrating IIoT technologies into real production environments.

However, it is important to note that the study is not without its inherent limitations, which are characteristic of the bibliometric approach. Firstly, the analysis is exclusively based on data from the Scopus database. While this is justified in terms of scope and compatibility, it limits access to publications that are available in other databases, such as Web of Science or IEEE Xplore. Secondly, the study's exclusion of citation networks, patents, and gray literature may limit the breadth of the analysis. Thirdly, while VOSviewer offers a visual depiction of co-authorship and thematic links, it does not incorporate techniques for normalizing citations by year or thematic domain. This potential oversight may partially influence the relative weight assigned to older publications.

Future research should expand the analysis by combining data from different databases, integrating altmetric and citation network methods, and conducting a more in-depth study of the actual industrial implementation of IIoT solutions. An interdisciplinary approach would facilitate the tracking of both academic trends and the practical results of digital transformation in the food sector.

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